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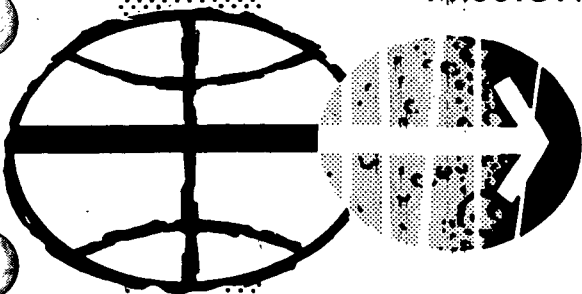
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ROUND TRIP LANDING MISSIONS TO THE ASTEROID EROS, 1981 OPPORTUNITY

Advanced Mission Design Branch

MISSION PLANNING AND ANALYSIS DIVISION



MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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By Gregory A. Zambo
Advanced Mission Design Branch

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MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
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CONTENTS

Section	Page
SUMMARY	1
INTRODUCTION	2
SYMBOLS	2
PROCEDURE	3
RESULTS	4
CONCLUSIONS	5
REFERENCES	20

TABLES

Table		Page
I	1981-82 EARTH TO EROS ONE-WAY MINIMUM ΔV REQUIREMENTS	6
II	1982 EROS TO EARTH ONE-WAY MINIMUM ΔV REQUIREMENTS	7
III	1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DAYS AND FLIGHT TIMES	
	(a) Staytime at Eros \geq 0 days	8
	(b) Staytime at Eros \geq 5 days	9
	(c) Staytime at Eros \geq 10 days	10
	(d) Staytime at Eros \geq 15 days	11
	(e) Staytime at Eros \geq 20 days	12
	(f) Staytime at Eros \geq 25 days	13
	(g) Staytime at Eros \geq 30 days	14
IV	VEHICLE CONFIGURATIONS AND COST COMPARISON (5000-LB PAYLOAD)	15

FIGURES

Figure		Page
1	Total mission ΔV versus total trip time for "fast" round trip landing missions to Eros in the 1981 opportunity	16
2	Characteristics and heliocentric sketch of mission A (fast mission)	17
3	Characteristics and heliocentric sketch of mission B (opposition class mission)	18
4	Characteristics and heliocentric sketch of mission C (conjunction class mission)	19

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SUMMARY

The asteroids may provide a key link in understanding the origin of the solar system and to this end a study of round trip landing missions to the asteroid Eros in the 1981 opportunity was conducted.

A comprehensive ΔV study of short staytime (0 to 30 days), short total trip time (10 to 160 days) round trip landing missions (fast missions) is presented. In addition, the characteristics of three selected round trip landing missions are described. These three missions have the following characteristics.

a. Mission A (fast mission): 120-day total trip time, 0-day staytime, 73 000-fps total mission ΔV

b. Mission B (opposition class): 380-day total trip time, 0-day staytime, 52 000-fps total mission ΔV

c. Mission C (conjunction class): 540-day total trip time, 175-day staytime, 39 000-fps total mission ΔV

A study using three different propulsion stages, the large-tank Agena, the chemical propulsion stage (CPS), and a nuclear stage was conducted to determine which and how many stages could perform each of the three missions. A payload of 5000 pounds was assumed. The propulsion requirements for mission A were found to be two large-tank Agenas and ten CPS's (or alternatively, two large-tank Agenas and five nuclear stages) while mission B required two large-tank Agenas and two CPS's. Mission C, the conjunction class mission, can be performed with one large-tank Agena and one CPS.

INTRODUCTION

As in reference 1,

As long as the asteroids were regarded as fragments of a broken-up planet, interest in them was limited. There are now good reasons to believe that the asteroidal belt represents an intermediate stage in the formation of planets. This links the present conditions in the asteroidal region with the epoch in which the earth and the other planets were accreting from interplanetary grains. Hence, in order to understand how the solar system originated it may be essential to explore the asteroids.

Round trip landing missions to the asteroid Eros (designated number 433) in the 1981 opportunity are considered using a 262- by 262-n. mi. altitude orbit at Earth departure and a 200- by 38 529-n. mi. altitude (1-day period) orbit at Earth return. The "landing" at Eros is actually a rendezvous with Eros, because of the small gravitational attraction of the asteroid. In fact, the concept has been discussed of capturing a small asteroid, bringing it back to Earth, and storing it in orbit about the Earth for later investigations (ref. 1). The three missions presented herein (missions A, B, and C) are representative of direct missions to Eros in the 1981 opportunity. Both two-impulse direct and three-impulse (intermediate heliocentric impulse) direct one-way trajectories were considered in this study.

The author acknowledges Stanley R. Sudol and Gus R. Babb of the Advanced Mission Design Branch for their assistance.

SYMBOLS

a	semimajor axis
e	eccentricity
I_{sp}	specific impulse
i	inclination relative to the ecliptic plane
M	mean anomaly
m_f	mass of usable propellant

m_s	burnout mass of stage
V_∞	magnitude of hyperbolic excess velocity vector
ΔV	magnitude of impulsive velocity-change vector
Ω	longitude of ascending node, heliocentric ecliptic system
ω	argument of periapsis, heliocentric ecliptic system

Subscripts

AE	arrive Earth
AR	arrive Eros
DE	depart Earth
DR	depart Eros
I	intermediate impulse

PROCEDURE

A computer program that minimizes one-way (Earth to Eros, or Eros to Earth) three-impulse ΔV was developed and used in this study. For a given launch date from the departure planet and flight time to the arrival planet, the sum of the departure ΔV , the intermediate impulse ΔV , and the arrival ΔV is minimized as a function of four independent variables: the position vector (dimensioned three) of the intermediate impulse, and the time from the departure planet to the intermediate impulse. A gradient method is used in the minimization process. The two-impulse one-way ΔV (Lambert's solution) is also calculated by the program.

This program uses an analytic Earth ephemeris based on reference 2 and a two-body motion ephemeris for Eros ($a = 1.4581$ astronomical unit, $e = 0.2228$, $i = 10.828^\circ$, $\Omega = 304.012^\circ$, $\omega = 178.084^\circ$, and $M = 238.913^\circ$ on January 6, 1941). A 262- by 262-n. mi. altitude orbit at Earth departure and a 200- by 38 529-n. mi. altitude capture orbit at Earth return were used in this study. The ΔV on arrival at Eros was assumed to be equal to the V_∞ upon arrival at Eros and the ΔV on departure from Eros was assumed to be equal to the V_∞ upon departure from Eros. A massless planet model (V_∞ vector defined as the heliocentric-transfer-conic velocity vector minus the velocity vector of the planet) was assumed throughout. Impulsive (ideal) ΔV 's and collinear burns at Earth departure, Eros arrival, Eros departure, and Earth arrival were also assumed throughout. Only one-way trajectories with transfer angles of less than 360° were considered.

The propulsion stages used herein were defined as follows:

- a. Large-tank Agena: $m_s = 1985$ pounds; $m_f = 35\ 000$ pounds;
 $I_{sp} = 292.5$ seconds
- b. CPS: $m_s = 60\ 000$ pounds; $m_f = 540\ 000$ pounds; $I_{sp} = 460$ seconds
- c. Nuclear stage: $m_s = 88\ 000$ pounds; $m_f = 300\ 000$ pounds;
 $I_{sp} = 784$ seconds

RESULTS

Table I presents Earth to Eros one-way minimum two-impulse and three-impulse ΔV requirements. In generating this table, only arrival Julian dates at Eros of 2 444 960 through 2 445 020, in increments of 5 days, and Earth to Eros flight times of 5 days through 100 days, in increments of 5 days, were considered.

Table II presents Eros to Earth one-way minimum two-impulse and three-impulse ΔV requirements. In generating this table, only departure from Eros Julian dates of 2 444 980 through 2 445 040, in increments of 5 days, and Eros to Earth flight times of 5 days through 100 days, in increments of 5 days, were considered. In tables I and II, only one-way legs with a minimum three-impulse ΔV of less than 900 000 fps are presented.

Table III presents the launch dates, the flight times, and the two-impulse and three-impulse minimum total mission ΔV 's for round trip missions. On each subtable of table III, the staytime at Eros is held fixed and the total trip time is varied. Each mission of table III was generated by choosing from all possible combinations of one-way trajectories from tables I and II, the round trip mission having, for the given minimum staytime and the given total trip time, the minimum total mission ΔV . Staytimes of 0 through 30 days, in increments of 5 days, and total trip times of 10 through 160 days, in increments of 5 days, are presented in table III.

Figure 1 graphically presents the table III results. Minimum total mission ΔV is plotted against total trip time, with the contour lines being lines of fixed minimum staytime at Eros. No difference between two-impulse and three-impulse total mission ΔV was found, therefore figure 1 represents identically both two-impulse and three-impulse round trip missions.

Three missions representative of the 1981 opportunity were selected and their characteristics are presented in figures 2, 3, and 4. Mission A, a "fast mission" to Eros, is represented in figure 2. This mission has a

0-day staytime at Eros and is seen to be the 120-day total trip time mission of table III(a). Mission B, an "opposition class" mission to Eros, is characterized in figure 3 while mission C, a "conjunction class" mission to Eros, is shown in figure 4.

Table IV presents the vehicle configurations capable of performing each of three aforementioned missions. A gross cost comparison is also presented.

CONCLUSIONS

The "fast mission" to Eros (120-day total trip time) required 73 000-fps total mission ΔV and is too costly to be considered seriously. The "opposition class" mission (380-day total trip time) requires 52 000-fps total mission ΔV and can be performed with two large-tank Agenas and two CPS's. The "conjunction class" mission (540-day total trip time) requires 39 000-fps total mission ΔV and, although 160 days longer in total trip time than the "opposition class" mission, it requires only one large-tank Agena and one CPS. Furthermore, it has a staytime at Eros of 175 days as compared to the 0-day staytime of the "opposition class" mission.

For an unmanned (5000-lb payload) mission to Eros in the 1981 opportunity, a cost consideration dictates the "conjunction class" mission as the obvious choice.

TABLE I.- 1981-82 EARTH TO EROS ONE-WAY MINIMUM ΔV REQUIREMENTS

JDDE = Julian date of Earth departure - 2 440 000

TFL = Earth to Eros flight time, days

DV2 = Two-impulse one-way ΔV requirement = $\Delta V_{DE} + \Delta V_{AR}$ fpsDV3 = Three-impulse one-way ΔV requirement = $\Delta V_{DE} + \Delta V_I + \Delta V_{AR}$ fps

262-n, mi. altitude at Earth departure.

JDDE	TFL	DV2	DV3	JDDE	TFL	DV2	DV3	JDDE	TFL	DV2	DV3
4985	5	849882	848882	4995	35	329060	329060	4995	55	39530	39530
4990	5	506193	506193	4990	35	279070	279070	4990	55	42491	42491
4995	5	319702	319702	4995	35	227351	227351	4995	55	44921	44921
4990	10	793438	793438	4990	35	174749	174749	4990	55	96313	96313
4995	10	605805	605605	4995	35	122975	122975	4995	55	131050	131050
4990	10	419820	419820	4990	35	76332	76332	4990	60	235352	235352
4995	10	248317	248317	4995	35	48252	48252	4995	60	212623	212623
4990	10	152267	152267	4990	35	61545	61545	4990	60	188127	188127
4995	10	237934	237934	4995	35	156843	156843	4995	60	161994	161994
4990	15	885992	885992	4990	35	592323	592323	4990	60	134569	134569
4995	15	705560	705560	4995	40	364456	364456	4995	60	106479	106479
4990	15	450644	450644	4990	40	328241	328241	4990	60	78914	78914
4995	15	527371	527371	4995	40	287359	287359	4995	60	54412	54412
4990	15	402345	402345	4990	40	244342	244342	4990	60	38444	38444
4995	15	278458	278458	4995	40	19844	19844	4995	60	40284	40284
4990	15	164538	164538	4990	40	154123	154123	4990	60	59495	59495
4995	15	99420	99420	4995	40	109384	109384	4995	60	87498	87498
4990	20	745352	745352	4990	40	67257	67257	4990	60	119272	119272
4995	20	663368	663368	4995	40	44800	44800	4995	60	215028	215028
4990	20	577192	577192	4990	40	30637	30637	4990	60	172475	172475
4995	20	485222	485222	4995	40	135788	135788	4995	60	149025	149025
4990	20	395229	395229	4990	40	83748	83748	4990	60	124394	124394
4995	20	301579	301579	4995	45	323255	323255	4995	60	99143	99143
4990	20	208958	208958	4990	45	290207	290207	4990	60	74369	74369
4995	20	124148	124148	4995	45	254728	254728	4995	60	52359	52359
4990	20	74919	74919	4990	45	217176	217176	4990	60	37988	37988
4995	20	116606	116606	4995	45	178066	178066	4995	60	34584	34584
4990	20	192862	192862	4990	45	138194	138194	4990	60	55030	55030
4995	20	594734	594734	4995	45	99030	99030	4995	60	80245	80245
4990	20	529640	529640	4990	45	49039	49039	4990	60	109241	109241
4995	20	161345	161345	4995	45	42421	42421	4995	60	197470	197470
4990	20	37003	37003	4990	45	2923	2923	4990	60	179000	179000
4995	20	31521	31521	4995	45	79956	79956	4995	60	159033	159033
4990	20	241849	241849	4990	45	11584	11584	4990	60	137033	137033
4995	20	168120	168120	4995	45	16225	16225	4995	60	115827	115827
4990	20	100975	100975	4990	50	288316	288316	4990	60	92853	92853
4995	20	61498	61498	4995	50	259438	259438	4995	60	70498	70498
4990	20	86768	86768	4990	50	228327	228327	4990	60	50446	50446
4995	20	151096	151096	4995	50	195278	195278	4995	60	37497	37497
4990	20	868138	868138	4990	50	160756	160756	4990	60	37268	37268
4995	20	871118	871118	4995	50	125502	125502	4995	60	31319	31319
4990	20	493914	493914	4990	50	90893	90893	4990	60	73363	73363
4995	20	440674	440674	4995	50	60044	60044	4995	60	10577	10577
4990	20	384302	384302	4990	50	40740	40740	4990	60	10377	10377
4995	20	325320	325320	4995	50	45384	45384	4995	60	165828	165828
4990	20	264398	264398	4990	50	71598	71598	4990	60	147451	147451
4995	20	202518	202518	4995	50	106806	106806	4995	60	126172	126172
4990	20	141522	141522	4990	50	145118	145118	4990	60	108016	108016
4995	20	84283	84283	4995	50	259478	259478	4995	60	87390	87390
4990	20	53420	53420	4990	50	23396	23396	4990	60	67162	67162
4995	20	21707	21707	4995	50	204496	204496	4995	60	49197	49197
4990	20	123785	123785	4990	50	177200	177200	4990	60	36445	36445
4995	20	185054	185054	4995	50	145516	145516	4995	60	2612	2612
4990	20	707816	707816	4990	50	115131	115131	4990	60	86542	86542
4995	20	421385	421385	4995	50	84327	84327	4995	60	53005	53005
4990	20	376647	376647	4990	50	58919	58919	4990	60	172714	172714
4995	20	154775	154775	4995	60	45397	45397	4995	60	136240	136240
4990	20	137501	137501	4990	60	4325	4325	4990	60	116812	116812
4995	20	119766	119766	4995	60	41517	41517	4995	60	101098	101098
4990	20	101378	101378	4990	60	39928	39928	4990	60	86237	86237
4995	20	82616	82616	4995	60	37636	37636	4995	60	71639	71639
4990	20	64265	64265	4990	60	35460	35460	4990	60	57598	57598
4995	20	47957	47957	4995	60	34355	34355	4995	60	45160	45160
4990	20	36841	36841	4990	60	33988	33988	4990	60	36336	36336
4995	20	35451	35451	4995	60	32399	32399	4995	60	33928	33928
4990	20	45397	45397	4990	60	30940	30940	4990	60	32890	32890
4995	20	43828	43828	4995	60	29461	29461	4995	60	31461	31461
4990	20	84125	84125	4990	60	28002	28002	4990	60	30002	30002
4995	20	165291	165291	4995	60	26543	26543	4995	60	28543	28543
4990	20	14552	14552	4990	60	25084	25084	4990	60	27084	27084
4995	20	129057	129057	4995	60	23625	23625	4995	60	25625	25625
4990	20	12057	12057	4990	60	22166	22166	4990	60	24166	24166
4995	20	95487	95487	4995	60	20707	20707	4995	60	22707	22707
4990	20	85487	85487	4990	60	19248	19248	4990	60	21248	21248
4995	20	78449	78449	4995	60	17789	17789	4995	60	19789	19789
4990	20	61736	61736	4990	60	16330	16330	4990	60	18330	18330
4995	20	46888	46888	4995	60	14871	14871	4995	60	16871	16871
4990	20	36833	36833	4990	60	13412	13412	4990	60	15412	15412
4995	20	3388	3388	4995	60	11953	11953	4995	60	13953	13953
4990	20	59705	59705	4990	60	10494	10494	4990	60	12494	12494
4995	20	80388	80388	4995	60	9035	9035	4995	60	11035	11035
4990	20	163443	163443	4990	60	7576	7576	4990	60	9576	9576
4995	20	139370	139370	4995	60	6117	6117	4995	60	8117	8117
4990	20	12211	12211	4990	60	4658	4658	4990	60	6658	6658
4995	20	106278	106278	4995	60	3200	3200	4995	60	5200	5200
4990	20	90557	90557	4990	60	1741	1741	4990	60	3741	3741
4995	20	74805	74805	4995	60	28	28	4995	60	28	28
4990	20	59526	59526	4990	60	19	19	4990	60	19	19
4995	20	45962	45962	4995	60	10	10	4995	60	10	10
4990	20	34960	34960	4990	60	1	1	4990	60	1	1
4995	20	34355	34355	4995	60	0	0	4995	60	0	0
4990	20	41517	41517	4990	60	0	0	4990	60	0	0
4995	20	58082	58082	4995	60	0	0	4995	60	0	0
4990	20	75078	75078	4990	60	0	0	4990	60	0	0
4995	20	12279	12279	4995	60	0	0	4995	60	0	0
4990	20	136240	136240	4990	60	0	0	4990	60	0	0
4995	20	116812	116812	4995	60	0	0	4995	60	0	0
4990	20	101098	101098	4990	60						

TABLE II.- 1982 EROS TO EARTH ONE-WAY MINIMUM ΔV REQUIREMENTS

JDDR = Julian date of Eros departure - 2 440 000

TFL = Eros to Earth flight time, days

DV2 = Two-impulse one-way ΔV requirement = $\Delta V_{DR} + \Delta V_{AE}$ fpsDV3 = Three-impulse one-way ΔV requirement = $\Delta V_{DR} + \Delta V_1 + \Delta V_{AE}$ fps

200--by 38 529-n. mi. altitude (1 day period) parking orbit at Earth return

JDDR	TFL	DV2	DV3	JDDR	TFL	DV2	DV3	JDDR	TFL	DV2	DV3
5000	5	320196	320196	4990	35	95134	95134	5020	55	139008	139008
5005	5	514504	514504	4995	35	55869	55869	5025	55	167623	167623
5010	5	850370	850370	5000	35	46342	46342	5030	55	198085	198085
4995	10	228689	228689	5005	35	73894	73894	5035	55	224761	224761
5000	10	152566	152566	5010	35	119157	119147	5040	55	249405	249405
5005	10	250720	250720	5015	35	169694	169694	4980	60	106268	106268
5010	10	420618	420618	5020	35	221222	221222	4985	60	76078	76078
5015	10	605003	605003	5025	35	271971	271971	4990	60	56229	56229
5020	10	791097	791097	5030	35	320988	320988	4995	60	34186	34186
4995	15	93388	93388	5035	35	367630	367630	5000	60	34633	34633
5000	15	144752	144752	5040	35	411403	411403	5005	60	50278	50278
5005	15	164905	164905	4980	40	176938	176938	5010	60	73917	73917
5010	15	277093	277093	4985	40	124325	124325	5015	60	100596	100596
5015	15	399454	399454	4990	40	81201	81201	5020	60	127744	127744
5020	15	523171	523171	4995	40	48723	48723	5025	60	154324	154324
5025	15	645141	645141	5000	40	42424	42424	5030	60	179638	179638
5030	15	763710	763710	5005	40	66425	66425	5035	60	203316	203316
5035	15	877733	877733	5010	40	105278	105278	5040	60	225192	225192
4990	20	183266	183266	5015	40	136850	136850	4980	65	96212	96212
4995	20	104172	104172	5020	40	193325	193325	4985	65	68793	68793
5000	20	74461	74461	5025	40	232375	232375	4990	65	45785	45785
5005	20	123428	123428	5030	40	279217	279217	4995	65	32334	32334
5010	20	208526	208526	5035	40	319157	319157	5000	65	33631	33631
5015	20	297740	297740	4980	40	356472	356472	5005	65	47929	47929
5020	20	390135	390135	4985	40	177452	177452	5010	65	61822	61822
5025	20	481283	481283	4990	40	108148	108148	5015	65	93055	93055
5030	20	569791	569791	4995	40	73585	73585	5020	65	117457	117457
5035	20	654766	654766	5000	40	43485	43485	5025	65	141253	141253
5040	20	735480	735480	5005	40	37603	37603	5030	65	163888	163888
4980	25	874010	874010	5010	40	40842	40842	5035	65	185058	185058
4985	25	869730	869730	5015	40	54680	54680	5040	65	204700	204700
4990	25	141105	141105	5020	40	132735	132735	4980	70	87538	87538
4995	25	80806	80806	5025	40	171607	171607	4985	70	62488	62488
5000	25	65645	65645	5030	40	209792	209792	4990	70	42089	42089
5005	25	99533	99533	5035	40	246460	246460	4995	70	30855	30855
5010	25	165063	165063	5040	40	281070	281070	5000	70	32800	32800
5015	25	237443	237443	4980	50	313243	313243	5005	70	45925	45925
5020	25	310973	310973	4985	50	132208	132208	5010	70	65078	65078
5025	25	383426	383426	4990	50	95273	95273	5015	70	86593	86593
5030	25	453727	453727	4995	50	62273	62273	5020	70	108547	108547
5035	25	521063	521063	5000	50	37549	37549	5025	70	129956	129956
5040	25	584812	584812	5005	50	37504	37504	5030	70	159394	159394
4980	30	709865	709865	5010	50	56525	56525	5035	70	186394	186394
4985	30	723367	723367	5015	50	86318	86318	5040	70	187301	187301
4990	30	114078	114078	5020	50	119877	119877	4980	75	79974	79974
4995	30	65946	65946	5025	50	154168	154168	4985	75	57102	57102
5000	30	51995	51995	5030	50	187794	187794	4990	75	38992	38992
5005	30	84296	84296	5035	50	219985	219985	4995	75	29664	29664
5010	30	138024	138024	5040	50	250256	250256	5000	75	32100	32100
5015	30	192737	192737	4980	50	278281	278281	5005	75	41186	41186
5020	30	258500	258500	4985	50	118082	118082	5010	75	61521	61521
5025	30	318392	318392	4990	50	84774	84774	5015	75	80954	80954
5030	30	376376	376376	4995	50	55429	55429	5020	75	100719	100719
5035	30	431748	431748	5000	50	36534	36534	5025	75	120113	120113
5040	30	483958	483958	5005	50	35903	35903	5030	75	138527	138527
4980	35	573625	573625	5010	50	53046	53046	5035	75	155918	155918
4985	35	145253	145253	5015	50	72538	72538	5040	75	172618	172618
				5020	50	109349	109349	4980	80	73317	73317
				5025	50	145253	145253				
				5030	50	187155	187155				
				5035	50	224761	224761				
				5040	50	264700	264700				
				4980	85	47929	47929				
				4985	85	61822	61822				
				4990	85	73585	73585				
				4995	85	86318	86318				
				5000	85	93055	93055				
				5005	85	100596	100596				
				5010	85	108148	108148				
				5015	85	117457	117457				
				5020	85	127744	127744				
				5025	85	139008	139008				
				5030	85	151403	151403				
				5035	85	164905	164905				
				5040	85	179638	179638				
				4980	90	42089	42089				
				4985	90	47929	47929				
				4990	90	53055	53055				
				4995	90	584812	584812				
				5000	90	647010	647010				
				5005	90	713426	713426				
				5010	90	786730	786730				
				5015	90	864812	864812				
				5020	90	947748	947748				
				5025	90	103625	103625				
				5030	90	113024	113024				
				5035	90	123024	123024				
				5040	90	133625	133625				
				4980	95	41186	41186				
				4985	95	45785	45785				
				4990	95	50278	50278				
				4995	95	54929	54929				
				5000	95	59759	59759				
				5005	95	64780	64780				
				5010	95	69980	69980				
				5015	95	75459	75459				
				5020	95	81199	81199				
				5025	95	87209	87209				
				5030	95	93509	93509				
				5035	95	100096	100096				
				5040	95	106996	106996				
				4980	100	48870	48870				
				4985	100	53046	53046				
				4990	100	573625	573625				
				4995	100	618924	618924				
				5000	100	666324	666324				
				5005	100	715824	715824				
				5010	100	767424	767424				
				5015	100	821224	821224				
				5020	100	877324	877324				
				5025	100	935824	935824				

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES

(a) Staytime at Eros ≥ 0 days

TTT = Total trip time, days

DV2 = Total mission ΔV , two-impulseDV3 = Total mission ΔV , three-impulse

JDDE = Julian date of Earth departure - 2 440 000

T1 = Earth to Eros flight time, days

S = Staytime at Eros, days

T2 = Eros to Earth flight time, days

JDDR = Julian date of Eros departure - 2 440 000

TTT	DV2	DV3	TWO-IMPULSE					THREE-IMPULSE				
			JDDE	T1	S	T2	JDDR	JDDE	T1	S	T2	JDDR
10	639898	639898	4995	5	0	5	5000	4995	5	0	5	5000
15	472268	472268	4995	5	0	10	5000	4995	5	0	10	5000
20	304833	304833	4990	10	0	10	5000	4990	10	0	10	5000
25	251655	251655	4990	10	0	15	5000	4990	10	0	15	5000
30	198808	198808	4985	15	0	15	5000	4985	15	0	15	5000
35	173881	173881	4985	15	0	20	5000	4985	15	0	20	5000
40	149380	149380	4980	20	0	20	5000	4980	20	0	20	5000
45	135484	135484	4980	20	0	25	5000	4980	20	0	25	5000
50	122063	122063	4975	25	0	25	5000	4975	25	0	25	5000
55	113493	113493	4975	25	0	30	5000	4975	25	0	30	5000
60	105415	105415	4970	30	0	30	5000	4970	30	0	30	5000
65	99762	99762	4970	30	0	35	5000	4970	30	0	35	5000
70	94594	94594	4965	35	0	35	5000	4965	35	0	35	5000
75	90676	90676	4965	35	0	40	5000	4965	35	0	40	5000
80	87224	87224	4960	40	0	40	5000	4960	40	0	40	5000
85	84403	84403	4960	40	0	45	5000	4960	40	0	45	5000
90	82024	82024	4955	45	0	45	5000	4955	45	0	45	5000
95	79925	79925	4955	45	0	50	5000	4955	45	0	50	5000
100	78244	78244	4950	50	0	50	5000	4950	50	0	50	5000
105	76640	76640	4950	50	0	55	5000	4950	50	0	55	5000
110	75383	75383	4950	50	0	60	5000	4950	50	0	60	5000
115	74173	74173	4945	55	0	60	5000	4945	55	0	60	5000
120	73161	73161	4945	55	0	65	5000	4945	55	0	65	5000
125	72275	72275	4940	60	0	65	5000	4940	60	0	65	5000
130	71444	71444	4940	60	0	70	5000	4940	60	0	70	5000
135	70744	70744	4940	60	0	75	5000	4940	60	0	75	5000
140	70088	70088	4935	65	0	75	5000	4935	65	0	75	5000
145	69484	69484	4935	65	0	80	5000	4935	65	0	80	5000
150	68953	68953	4935	65	0	85	5000	4935	65	0	85	5000
155	68462	68462	4930	70	0	85	5000	4930	70	0	85	5000
160	67985	67985	4930	70	0	90	5000	4930	70	0	90	5000

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(b) Staytime at Eros ≥ 5 days

TTT	DV2	DV3	TWO-IMPULSE					THREE-IMPULSE				
			JUDE	T1	S	T2	JDDR	JUDE	T1	S	T2	JDDR
15	826389	826389	4990	5	5	5	5000	4990	5	5	5	5000
20	568513	568513	4985	10	5	5	5000	4985	10	5	5	5000
25	400883	400883	4985	10	5	10	5000	4985	10	5	10	5000
30	317104	317104	4980	15	5	10	5000	4980	15	5	10	5000
35	263926	263926	4980	15	5	15	5000	4980	15	5	15	5000
40	222848	222848	4985	15	5	20	5005	4985	15	5	20	5005
45	198347	198347	4980	20	5	20	5005	4980	20	5	20	5005
50	174452	174452	4980	20	5	25	5005	4980	20	5	25	5005
55	159215	159215	4980	20	5	30	5005	4980	20	5	30	5005
60	145794	145794	4975	25	5	30	5005	4975	25	5	30	5005
65	135392	135392	4975	25	5	35	5005	4975	25	5	35	5005
70	127314	127314	4970	30	5	35	5005	4970	30	5	35	5005
75	119845	119845	4970	30	5	40	5005	4970	30	5	40	5005
80	114262	114262	4970	30	5	45	5005	4970	30	5	45	5005
85	109094	109094	4965	35	5	45	5005	4965	35	5	45	5005
90	104777	104777	4965	35	5	50	5005	4965	35	5	50	5005
95	101325	101325	4960	40	5	50	5005	4960	40	5	50	5005
100	97886	97886	4960	40	5	55	5005	4960	40	5	55	5005
105	95078	95078	4960	40	5	60	5005	4960	40	5	60	5005
110	92699	92699	4955	45	5	60	5005	4955	45	5	60	5005
115	90350	90350	4955	45	5	65	5005	4955	45	5	65	5005
120	88346	88346	4955	45	5	70	5005	4955	45	5	70	5005
125	86607	86607	4955	45	5	75	5005	4955	45	5	75	5005
130	84926	84926	4950	50	5	75	5005	4950	50	5	75	5005
135	83394	83394	4950	50	5	80	5005	4950	50	5	80	5005
140	82026	82026	4950	50	5	85	5005	4950	50	5	85	5005
145	80792	80792	4950	50	5	90	5005	4950	50	5	90	5005
150	79582	79582	4945	55	5	90	5005	4945	55	5	90	5005
155	78459	78459	4945	55	5	95	5005	4945	55	5	95	5005
160	77429	77429	4945	55	5	100	5005	4945	55	5	100	5005

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(c) Staytime at Eros ≥ 10 days

TTT	DV2	DV3	TWO-IMPULSE					THREE-IMPULSE				
			JDDE	T1	S	I2	JDDR	JDDE	T1	S	I2	JDDR
20	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
25	740016	740016	4980	10	10	5	5000	4980	10	10	5	5000
30	499037	499037	4985	10	10	10	5005	4985	10	10	10	5005
35	413222	413222	4985	10	10	15	5005	4985	10	10	15	5005
40	329443	329443	4980	15	10	15	5005	4980	15	10	15	5005
45	287966	287966	4980	15	10	20	5005	4980	15	10	20	5005
50	247576	247576	4975	20	10	20	5005	4975	20	10	20	5005
55	223681	223681	4975	20	10	25	5005	4975	20	10	25	5005
60	200508	200508	4970	25	10	25	5005	4970	25	10	25	5005
65	185271	185271	4970	25	10	30	5005	4970	25	10	30	5005
70	170579	170579	4965	30	10	30	5005	4965	30	10	30	5005
75	160177	160177	4965	30	10	35	5005	4965	30	10	35	5005
80	150226	150226	4960	35	10	35	5005	4960	35	10	35	5005
85	142757	142757	4960	35	10	40	5005	4960	35	10	40	5005
90	135682	135682	4955	40	10	40	5005	4955	40	10	40	5005
95	130099	130099	4955	40	10	45	5005	4955	40	10	45	5005
100	124871	124871	4950	45	10	45	5005	4950	45	10	45	5005
105	120554	120554	4950	45	10	50	5005	4950	45	10	50	5005
110	116569	116569	4945	50	10	50	5005	4945	50	10	50	5005
115	113130	113130	4945	50	10	55	5005	4945	50	10	55	5005
120	109773	109773	4965	35	10	75	5010	4965	35	10	75	5010
125	106321	106321	4960	40	10	75	5010	4960	40	10	75	5010
130	103190	103190	4960	40	10	80	5010	4960	40	10	80	5010
135	100410	100410	4960	40	10	85	5010	4960	40	10	85	5010
140	97923	97923	4960	40	10	90	5010	4960	40	10	90	5010
145	95544	95544	4955	45	10	90	5010	4955	45	10	90	5010
150	93308	93308	4955	45	10	95	5010	4955	45	10	95	5010
155	91291	91291	4955	45	10	100	5010	4955	45	10	100	5010
160	89610	89610	4950	50	10	100	5010	4950	50	10	100	5010

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(d) Staytime at Eros ≥ 15 days

TIT	DV2	DV3	TWO-IMPULSE					THREE-IMPULSE				
			JUDE	T1	S	T2	JDDR	JUDE	T1	S	T2	JDDR
25	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
30	924705	924705	4995	5	15	10	5015	4995	5	15	10	5015
35	668935	668935	4985	10	15	10	5010	4985	10	15	10	5010
40	525410	525410	4985	10	15	15	5010	4985	10	15	15	5010
45	441631	441631	4980	15	15	15	5010	4980	15	15	15	5010
50	371074	371074	4980	15	15	20	5010	4980	15	15	20	5010
55	329601	329601	4980	15	15	25	5010	4980	15	15	25	5010
60	289211	289211	4975	20	15	25	5010	4975	20	15	25	5010
65	262176	262176	4975	20	15	30	5010	4975	20	15	30	5010
70	239003	239003	4970	25	15	30	5010	4970	25	15	30	5010
75	220122	220122	4970	25	15	35	5010	4970	25	15	35	5010
80	205430	205430	4965	30	15	35	5010	4965	30	15	35	5010
85	191561	191561	4965	30	15	40	5010	4965	30	15	40	5010
90	180963	180963	4965	30	15	45	5010	4965	30	15	45	5010
95	170847	170847	4975	25	15	55	5015	4975	25	15	55	5015
100	162044	162044	4975	25	15	60	5015	4975	25	15	60	5015
105	153966	153966	4970	30	15	60	5015	4970	30	15	60	5015
110	146475	146475	4970	30	15	65	5015	4970	30	15	65	5015
115	140013	140013	4970	30	15	70	5015	4970	30	15	70	5015
120	134374	134374	4970	30	15	75	5015	4970	30	15	75	5015
125	129206	129206	4965	35	15	75	5015	4965	35	15	75	5015
130	124244	124244	4965	35	15	80	5015	4965	35	15	80	5015
135	119847	119847	4965	35	15	85	5015	4965	35	15	85	5015
140	115935	115935	4965	35	15	90	5015	4965	35	15	90	5015
145	112444	112444	4965	35	15	95	5015	4965	35	15	95	5015
150	108992	108992	4960	40	15	95	5015	4960	40	15	95	5015
155	105875	105875	4960	40	15	100	5015	4960	40	15	100	5015
160	103496	103496	4955	45	15	100	5015	4955	45	15	100	5015

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(e) Staytime at Eros ≥ 20 days

ITT	DV2	DV3	TWO-IMPULSE					THREE-IMPULSE				
			JDDC	I1	S	I2	JDDR	JDDC	I1	S	I2	JDDR
30	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
35	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
40	840438	840438	4980	10	20	10	5010	4980	10	20	10	5010
45	647771	647771	4985	10	20	15	5015	4985	10	20	15	5015
50	542422	542422	4990	10	20	20	5020	4990	10	20	20	5020
55	462278	462278	4980	15	20	20	5015	4980	15	20	20	5015
60	401981	401981	4980	15	20	25	5015	4980	15	20	25	5015
65	357920	357920	4985	15	20	30	5020	4985	15	20	30	5020
70	320642	320642	4985	15	20	35	5020	4985	15	20	35	5020
75	292745	292745	4985	15	20	40	5020	4985	15	20	40	5020
80	268244	268244	4980	20	20	40	5020	4980	20	20	40	5020
85	246526	246526	4980	20	20	45	5020	4980	20	20	45	5020
90	229087	229087	4980	20	20	50	5020	4980	20	20	50	5020
95	214727	214727	4980	20	20	55	5020	4980	20	20	55	5020
100	201306	201306	4975	25	20	55	5020	4975	25	20	55	5020
105	189242	189242	4975	25	20	60	5020	4975	25	20	60	5020
110	178945	178945	4975	25	20	65	5020	4975	25	20	65	5020
115	170045	170045	4975	25	20	70	5020	4975	25	20	70	5020
120	161967	161967	4970	30	20	70	5020	4970	30	20	70	5020
125	154199	154199	4970	30	20	75	5020	4970	30	20	75	5020
130	147371	147371	4970	30	20	80	5020	4970	30	20	80	5020
135	141341	141341	4970	30	20	85	5020	4970	30	20	85	5020
140	136004	136004	4970	30	20	90	5020	4970	30	20	90	5020
145	130836	130836	4965	35	20	90	5020	4965	35	20	90	5020
150	126114	126114	4965	35	20	95	5020	4965	35	20	95	5020
155	121955	121955	4965	35	20	100	5020	4965	35	20	100	5020
160	118503	118503	4960	40	20	100	5020	4960	40	20	100	5020

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Continued

(f) Staytime at Eros ≥ 25 days

TTT	DV2	DV3	TWO-IMPULSE					THREE-IMPULSE				
			JDOE	T1	S	T2	JDDR	JDOE	T1	S	T2	JDDR
35	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
40	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
45	964843	964843	4995	5	25	15	5025	4995	5	25	15	5025
50	771488	771488	4985	10	25	15	5020	4985	10	25	15	5020
55	633550	633550	4990	10	25	20	5025	4990	10	25	20	5025
60	535693	535693	4990	10	25	25	5025	4990	10	25	25	5025
65	470659	470659	4990	10	25	30	5025	4990	10	25	30	5025
70	417812	417812	4985	15	25	30	5025	4985	15	25	30	5025
75	371391	371391	4985	15	25	35	5025	4985	15	25	35	5025
80	336495	336495	4985	15	25	40	5025	4985	15	25	40	5025
85	309212	309212	4985	15	25	45	5025	4985	15	25	45	5025
90	284711	284711	4980	20	25	45	5025	4980	20	25	45	5025
95	262713	262713	4980	20	25	50	5025	4980	20	25	50	5025
100	244542	244542	4980	20	25	55	5025	4980	20	25	55	5025
105	229243	229243	4980	20	25	60	5025	4980	20	25	60	5025
110	215822	215822	4975	25	25	60	5025	4975	25	25	60	5025
115	202751	202751	4975	25	25	65	5025	4975	25	25	65	5025
120	191454	191454	4975	25	25	70	5025	4975	25	25	70	5025
125	181611	181611	4975	25	25	75	5025	4975	25	25	75	5025
130	172989	172989	4975	25	25	80	5025	4975	25	25	80	5025
135	164911	164911	4970	30	25	80	5025	4970	30	25	80	5025
140	157342	157342	4970	30	25	85	5025	4970	30	25	85	5025
145	150705	150705	4970	30	25	90	5025	4970	30	25	90	5025
150	144925	144925	4970	30	25	95	5025	4970	30	25	95	5025
155	139757	139757	4965	35	25	95	5025	4965	35	25	95	5025
160	134805	134805	4965	35	25	100	5025	4965	35	25	100	5025

TABLE III.- 1981-82 EROS ROUND TRIP MISSIONS: LAUNCH DATES AND FLIGHT TIMES - Concluded

(g) Staytime at Eros ≥ 30 days

TTT	DV2	DV3	TWO-IMPULSE					THREE-IMPULSE				
			JUDE	T1	S	T2	JDDR	JUDE	T1	S	T2	JDDR
40	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
45	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
50	999999	999999	4890	100	30	100	5020	4890	100	30	100	5020
55	889493	889493	4995	5	30	20	5030	4995	5	30	20	5030
60	722058	722058	4990	10	30	20	5030	4990	10	30	20	5030
65	605994	605994	4990	10	30	25	5030	4990	10	30	25	5030
70	528643	528643	4990	10	30	30	5030	4990	10	30	30	5030
75	473255	473255	4990	10	30	35	5030	4990	10	30	35	5030
80	420408	420408	4985	15	30	35	5030	4985	15	30	35	5030
85	378637	378637	4985	15	30	40	5030	4985	15	30	40	5030
90	345880	345880	4985	15	30	45	5030	4985	15	30	45	5030
95	319405	319405	4985	15	30	50	5030	4985	15	30	50	5030
100	294904	294904	4980	20	30	50	5030	4980	20	30	50	5030
105	273004	273004	4980	20	30	55	5030	4980	20	30	55	5030
110	254557	254557	4980	20	30	60	5030	4980	20	30	60	5030
115	238807	238807	4980	20	30	65	5030	4980	20	30	65	5030
120	225228	225228	4980	20	30	70	5030	4980	20	30	70	5030
125	211807	211807	4975	25	30	70	5030	4975	25	30	70	5030
130	200025	200025	4975	25	30	75	5030	4975	25	30	75	5030
135	189776	189776	4975	25	30	80	5030	4975	25	30	80	5030
140	180882	180882	4975	25	30	85	5030	4975	25	30	85	5030
145	172804	172804	4970	30	30	85	5030	4970	30	30	85	5030
150	165165	165165	4970	30	30	90	5030	4970	30	30	90	5030
155	158772	158772	4970	30	30	95	5030	4970	30	30	95	5030
160	153604	153604	4965	35	30	95	5030	4965	35	30	95	5030

TABLE IV. - VEHICLE CONFIGURATIONS AND COST COMPARISON
(5000-LB PAYLOAD)

Mission	A		B		C	
	Fast		Opposition class		Conjunction class	
Total trip time, days	120		380		540	
Staytime at Eros, days	0		0		175	
Total mission ΔV required, fps	73 000		52 000		39 000	
Vehicle configuration (stages capable of performing mission, in tandem)	^a 2 large-tank Agenas + 10 CPS		2 large-tank Agenas + 2 CPS		1 large-tank Agena + 1 CPS	
ΔV capability of vehicle configuration, fps	74 500		54 000		44 000	
Relative cost	10		2		1	

^aTwo large-tank Agenas and 5 nuclear stages can be used here instead (75 500 fps ΔV capability).

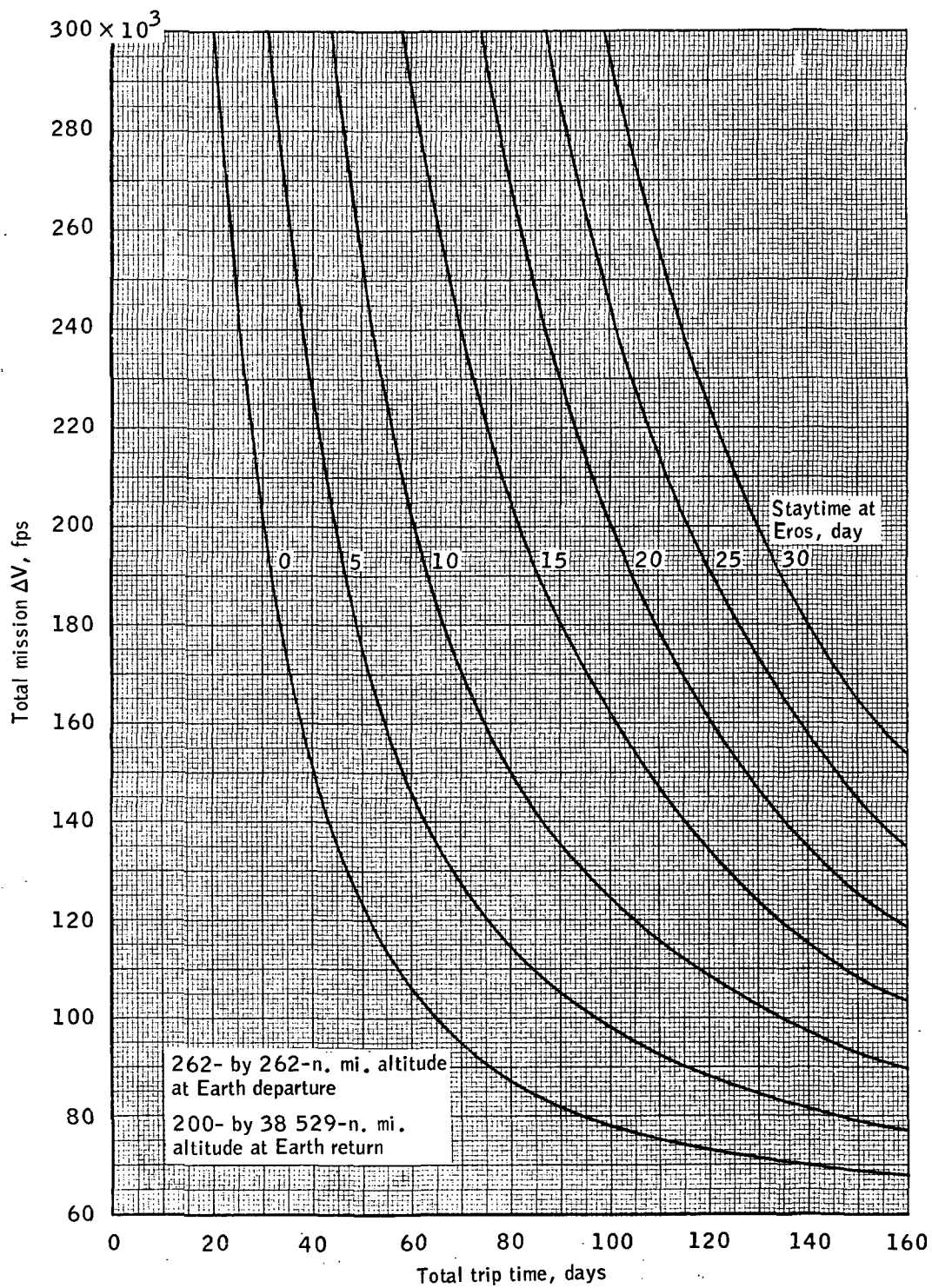


Figure 1.- Total mission ΔV versus total trip time for "fast" round trip landing missions to Eros in the 1981 opportunity.

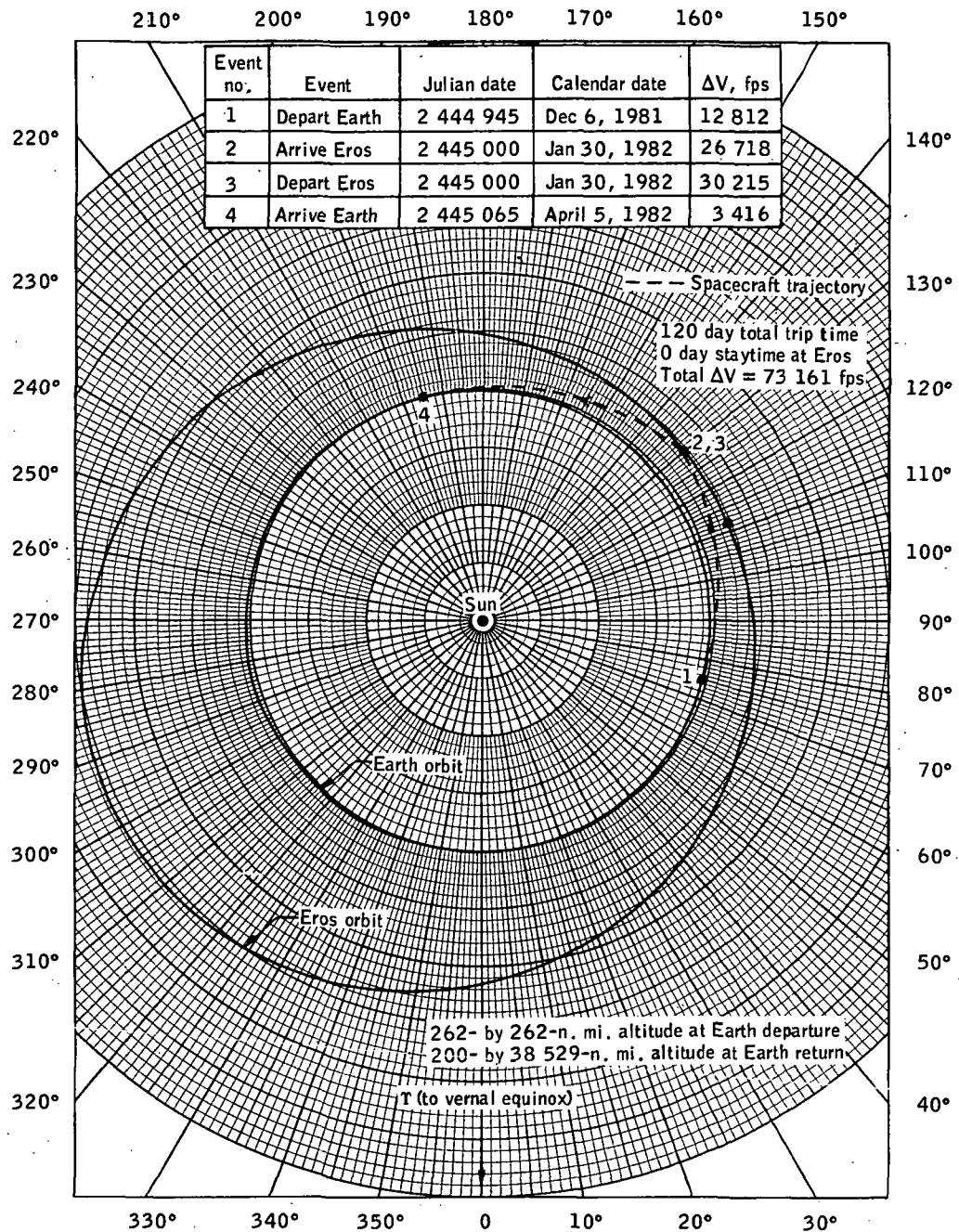


Figure 2.- Characteristics and heliocentric sketch of mission A (fast mission).

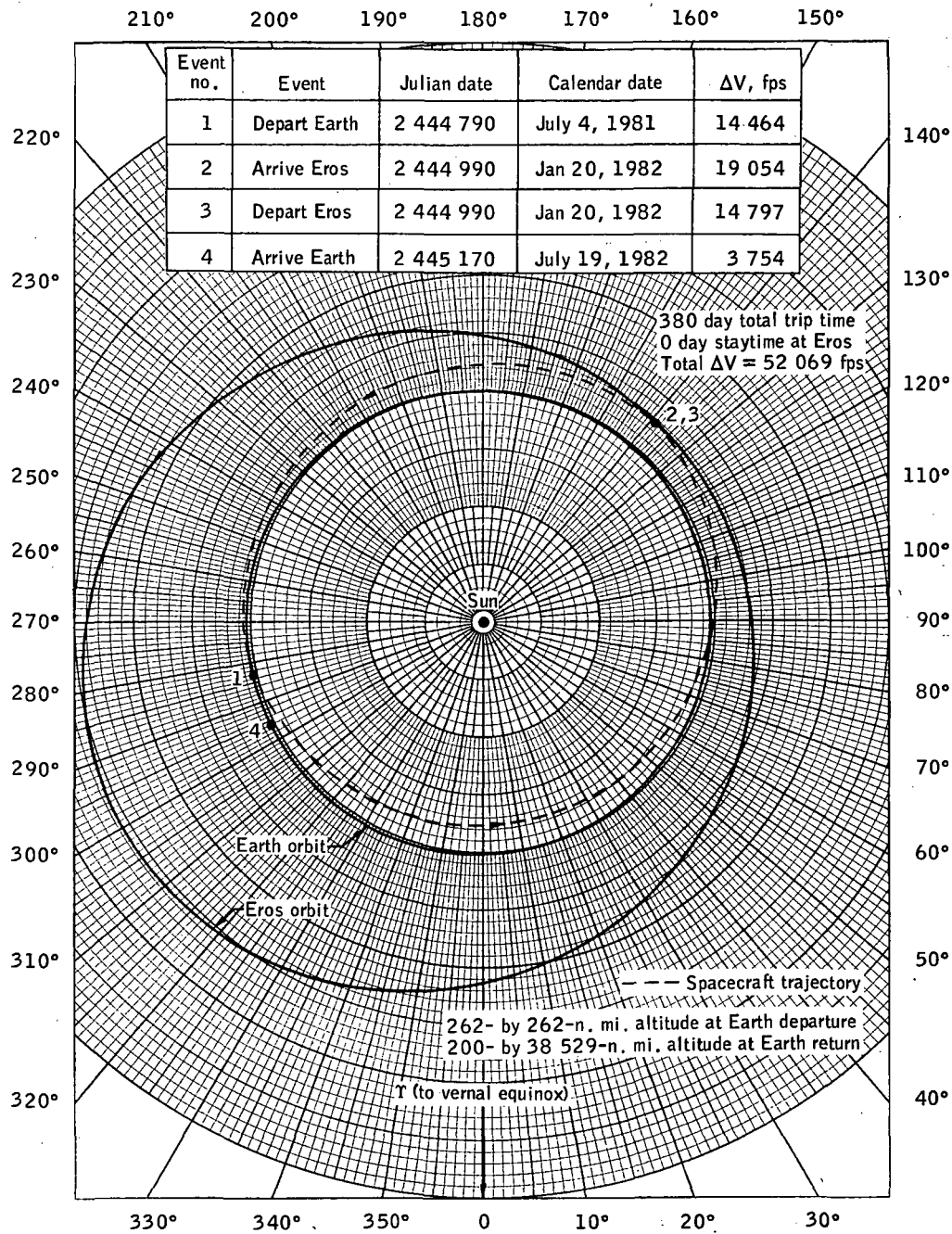


Figure 3.- Characteristics and heliocentric sketch of mission B (opposition class mission).

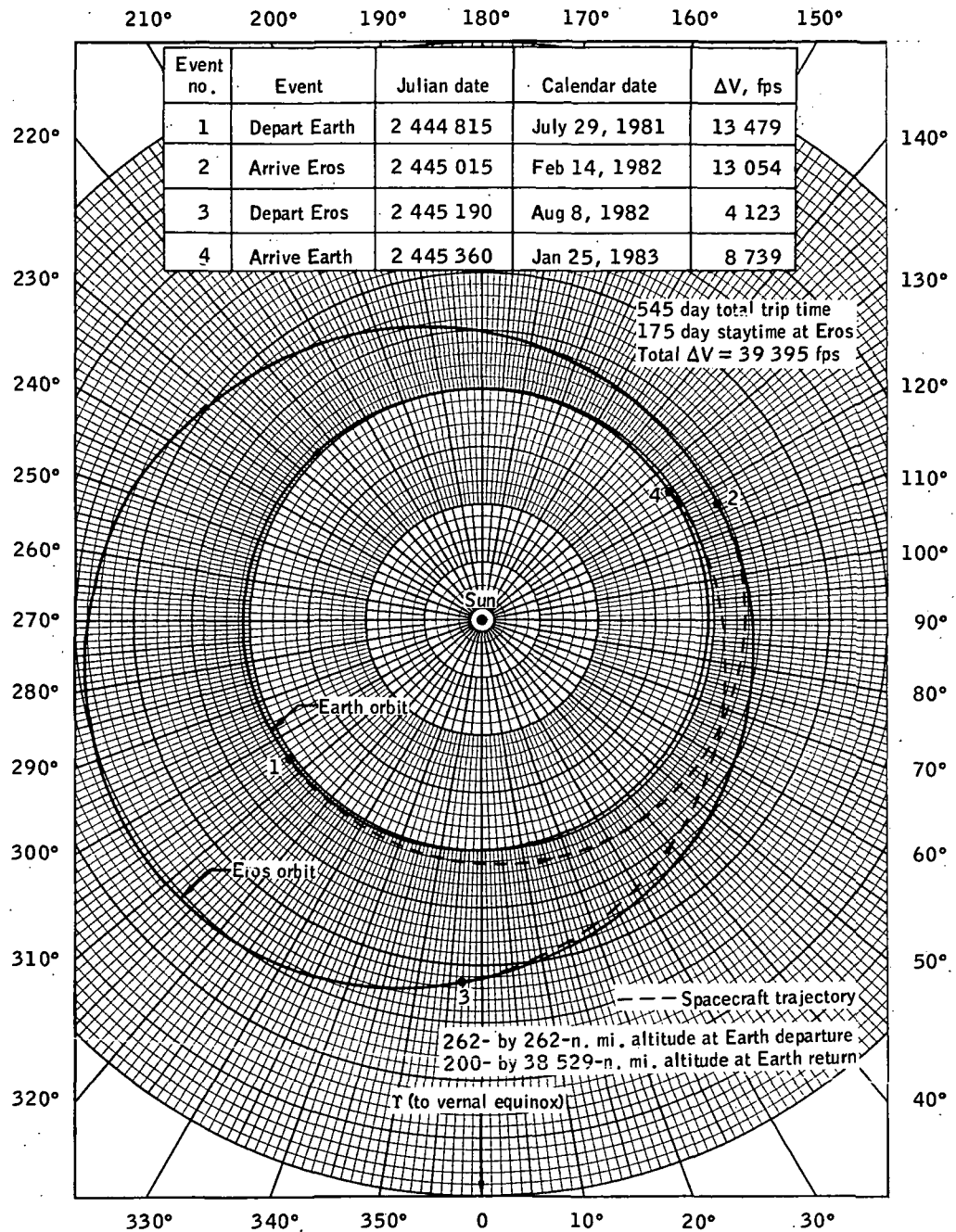


Figure 4.- Characteristics and heliocentric sketch of mission C (conjunction class mission).

REFERENCE

1. Alfven, H.; and Arrhenius, G.: Mission to an Asteroid. Science, Vol. 167, Jan. 9, 1970, pp. 139-141.